



# Galileo Antenna Failure and Mission Recovery

December 5, 1995

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California Institute of Technology

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12/05/95



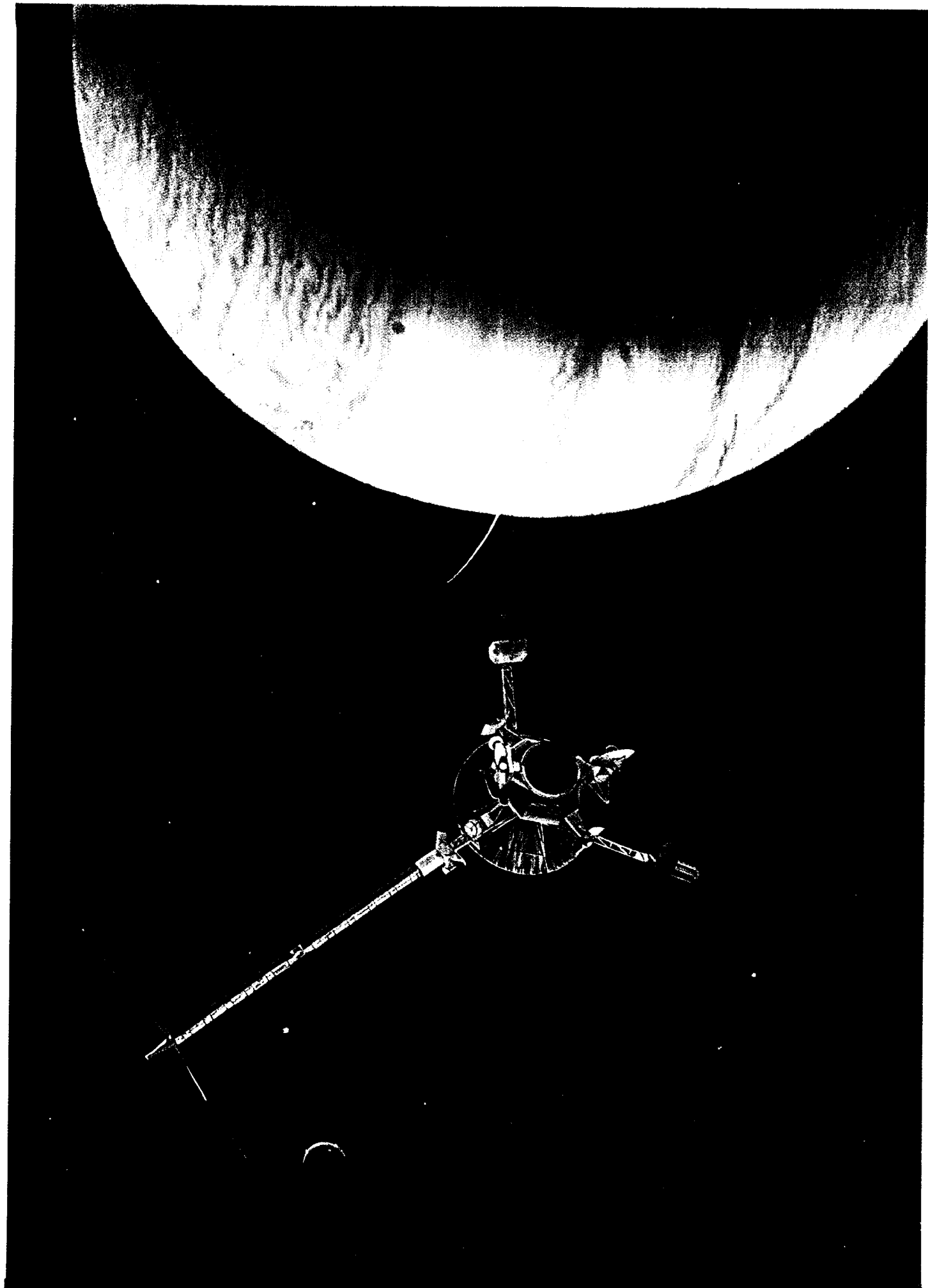
## Countdown:

1 day      13 hours      38 minutes

to Galileo Spacecraft Arrival at Jupiter\* !

\*Galileo Spacecraft Closest Io Approach at December 7, 1995 at 10:38 AM PST  
- Probe Atmospheric Entry and Relay on December 7, 1995 at 2:56 PM PST -

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# Background

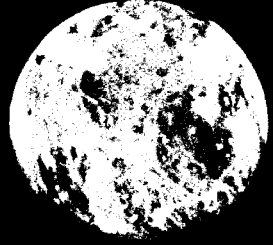
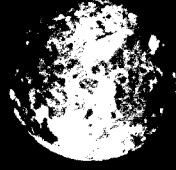
the Mission,  
the Spacecraft,  
and the High Gain Antenna

# PROJECT GALILEO WILL INVESTIGATE THE...

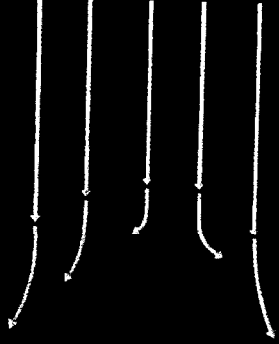


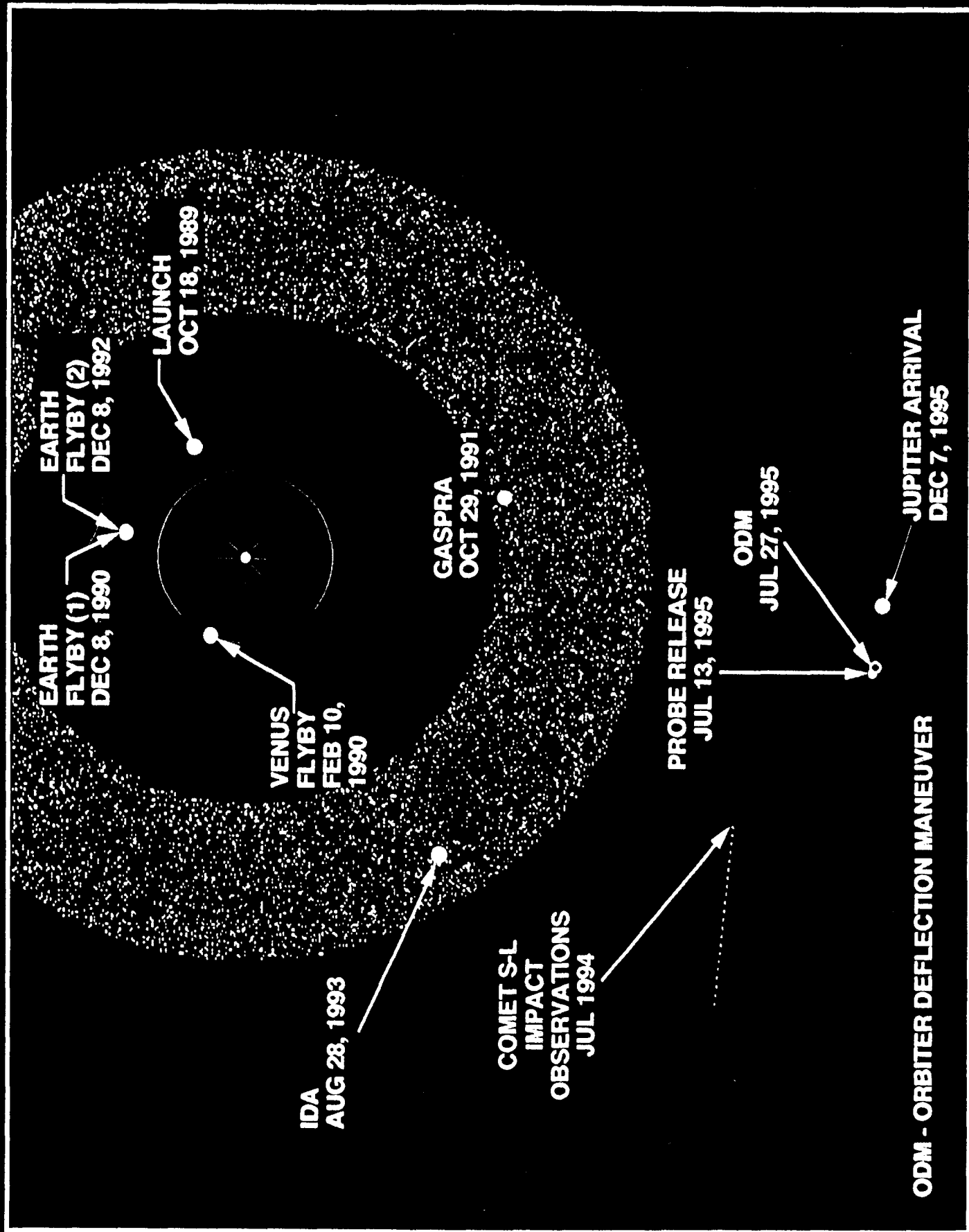
Chemical composition  
and physical state of  
Jupiter's atmosphere

Structure and physical dynamics of  
the Jovian magnetosphere



Chemical  
composition  
and physical  
states of the  
Jovian satellites







## Spacecraft Description



.Spacecraft consists of three elements:

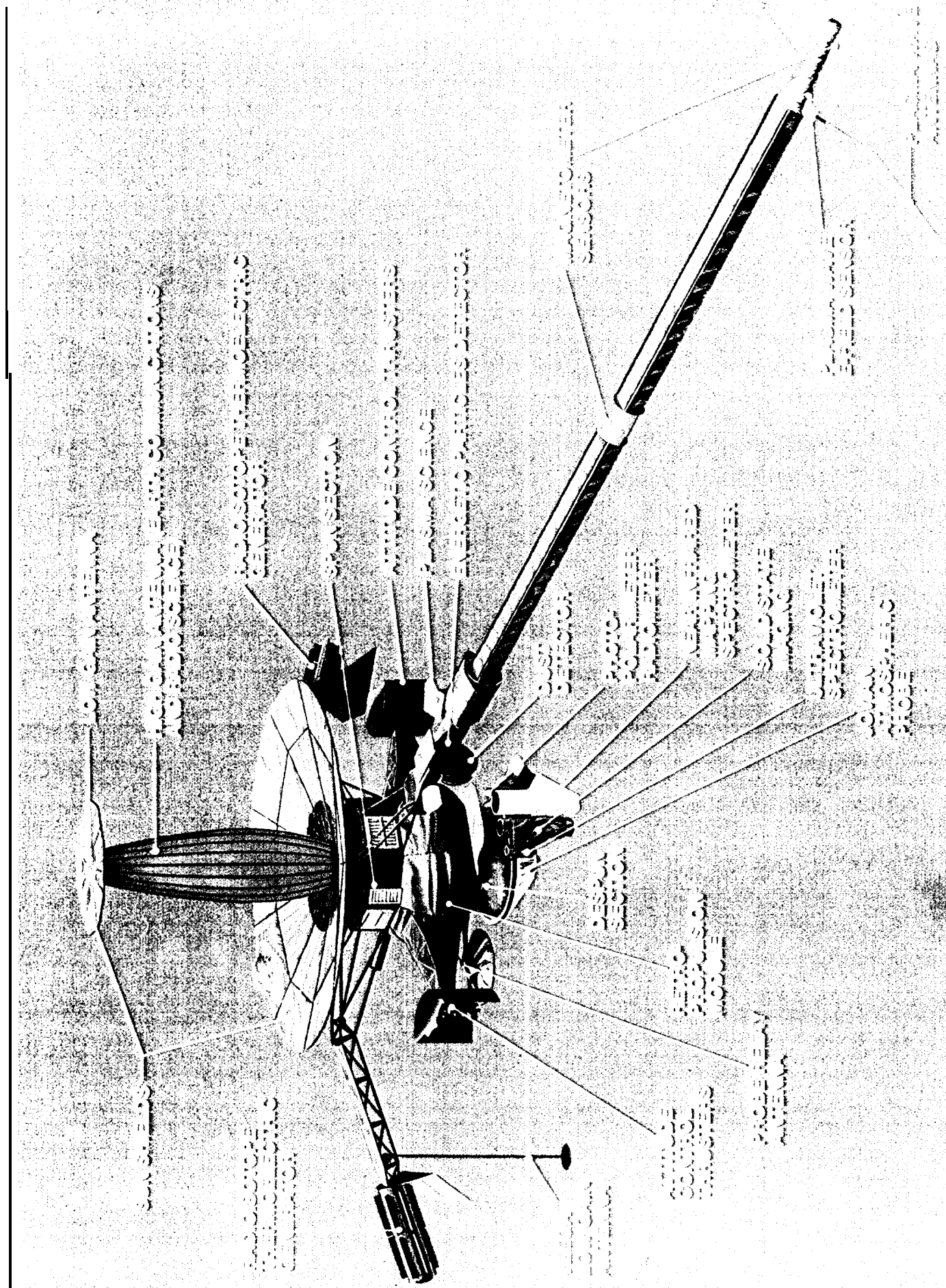
- atmospheric probe
- Spinning section (3 rpm nominal, 10 rpm max) with fields & particles instruments, S,/X band high gain ant, propulsion module, flight computer and other support systems
- Despun section with cameras and other remote sensors

.Orbitor weighed 2,223 kg and carries 12 experiments

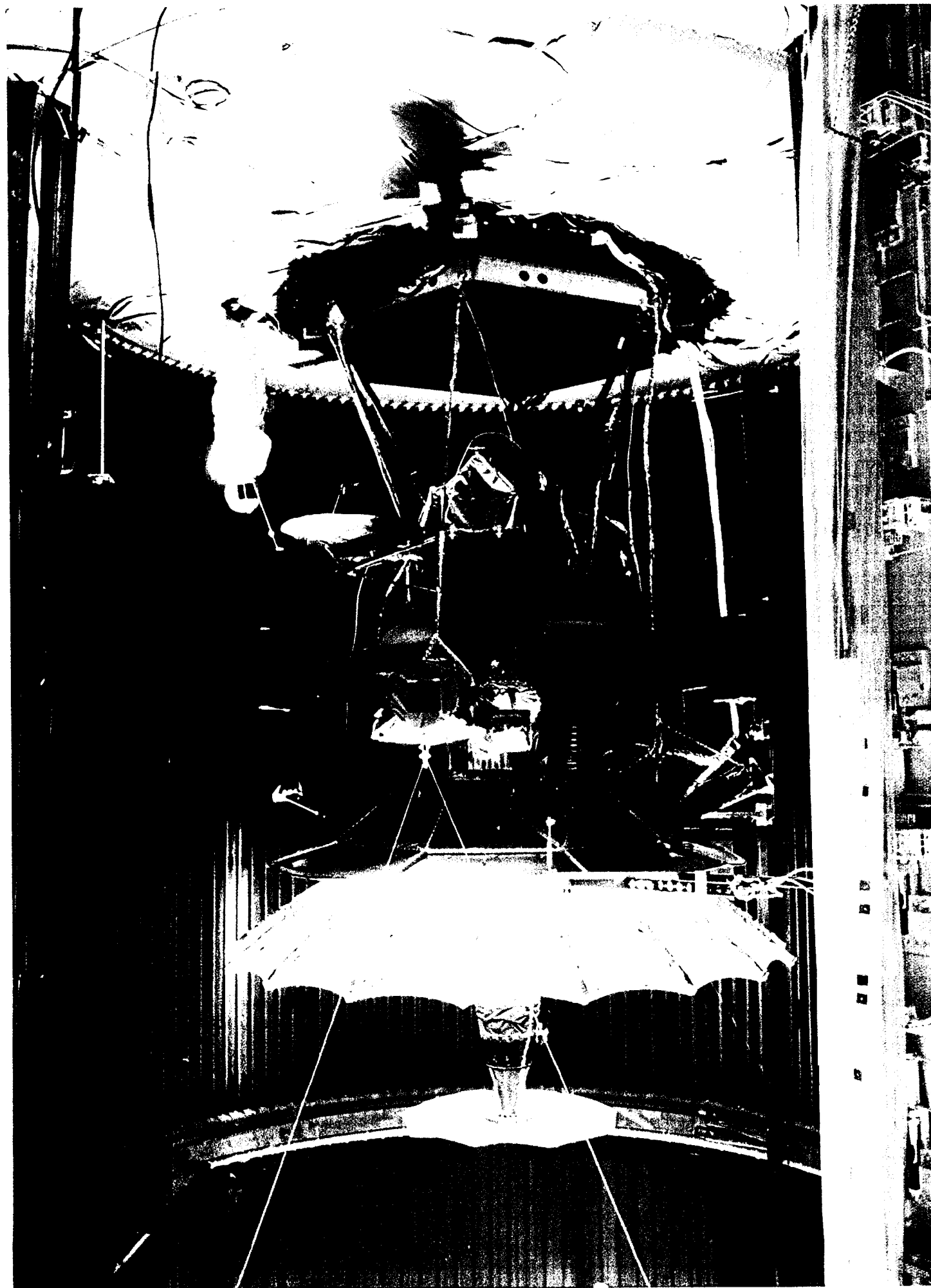
- Powered by radioisotopes thermoelectric generators (520 W)
- 20 W S-band transmitter with maximum 1.2 kbps data rate
- 20 W X-band transmitter with maximum 134 kbps data rate
- Forward and aft-pointing S-band low gain antennas (approximately 7 dBi gain)

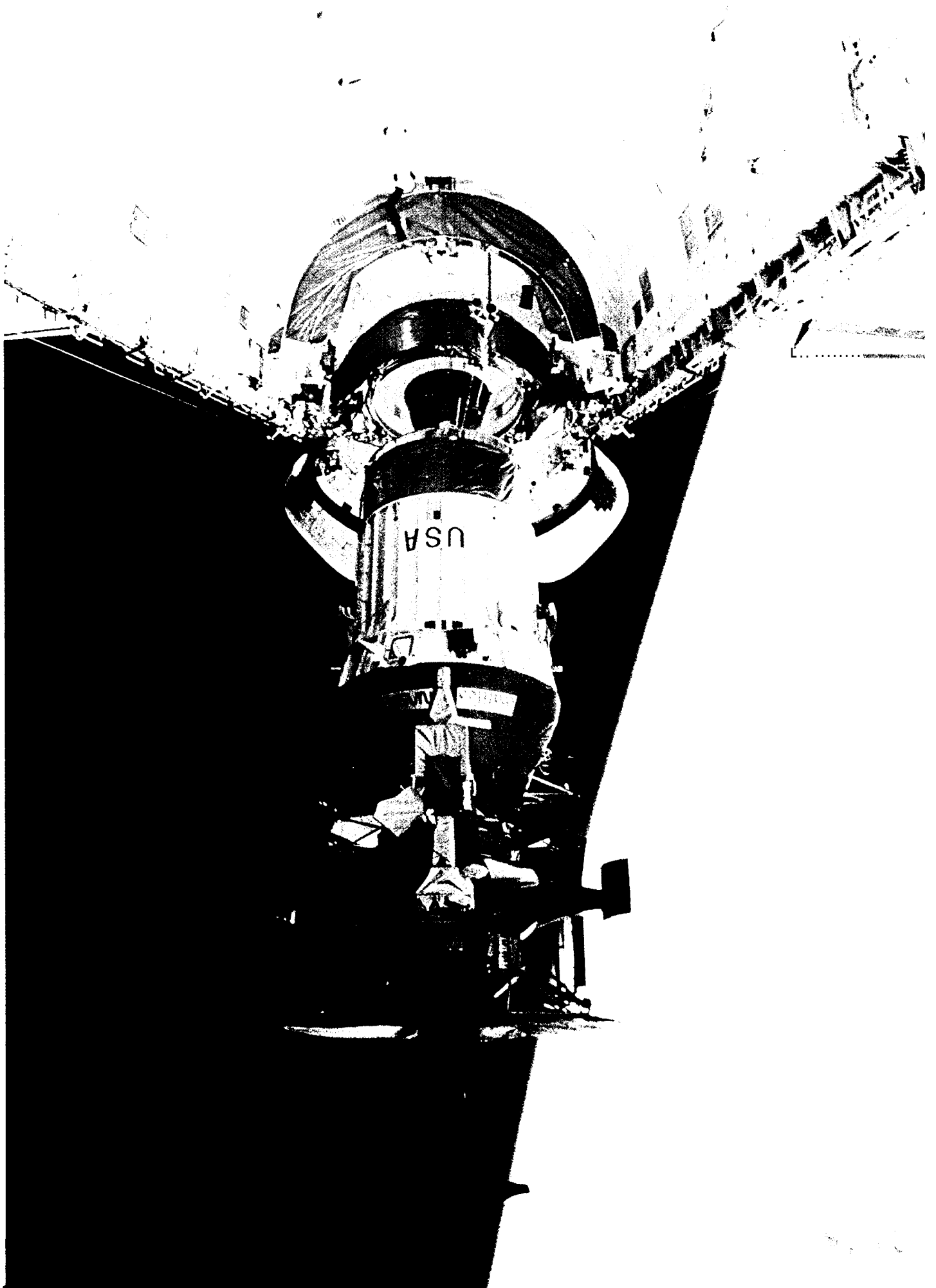
.Probe weighs 339 kg and carries 7 science experiments

- Probe mission duration is 40 to 75 minutes
- Powered by lithium-sulfur battery (730 watt-hours)

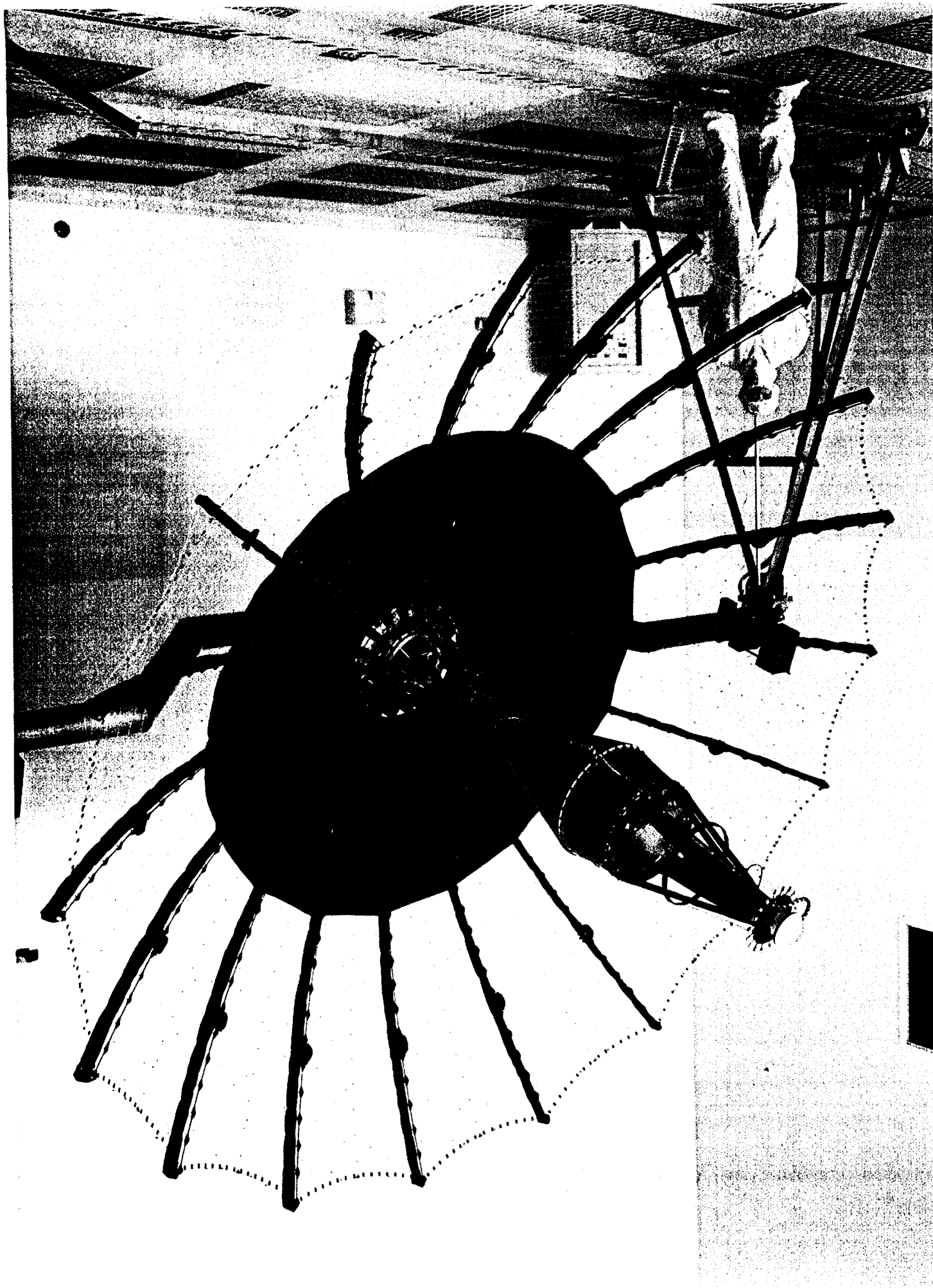


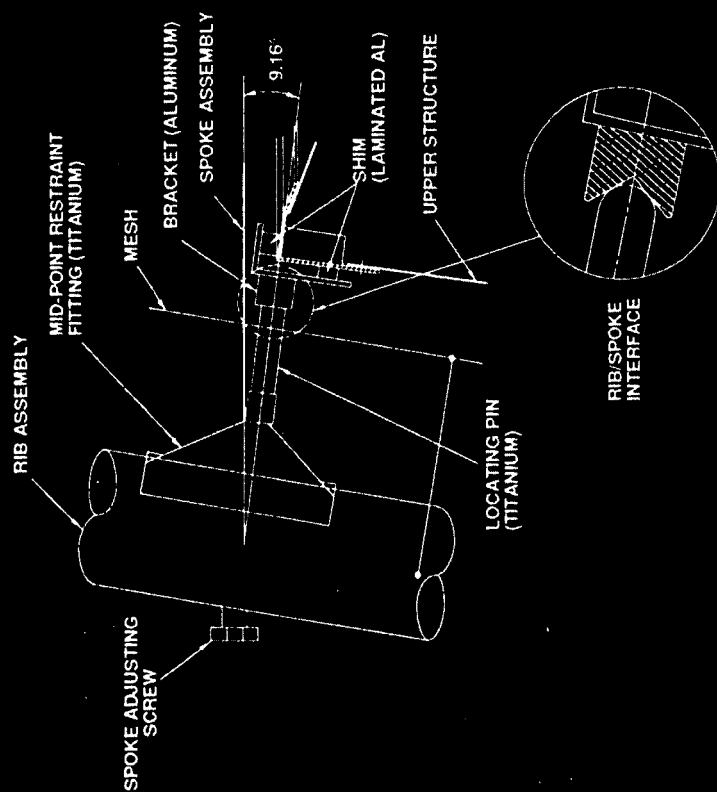
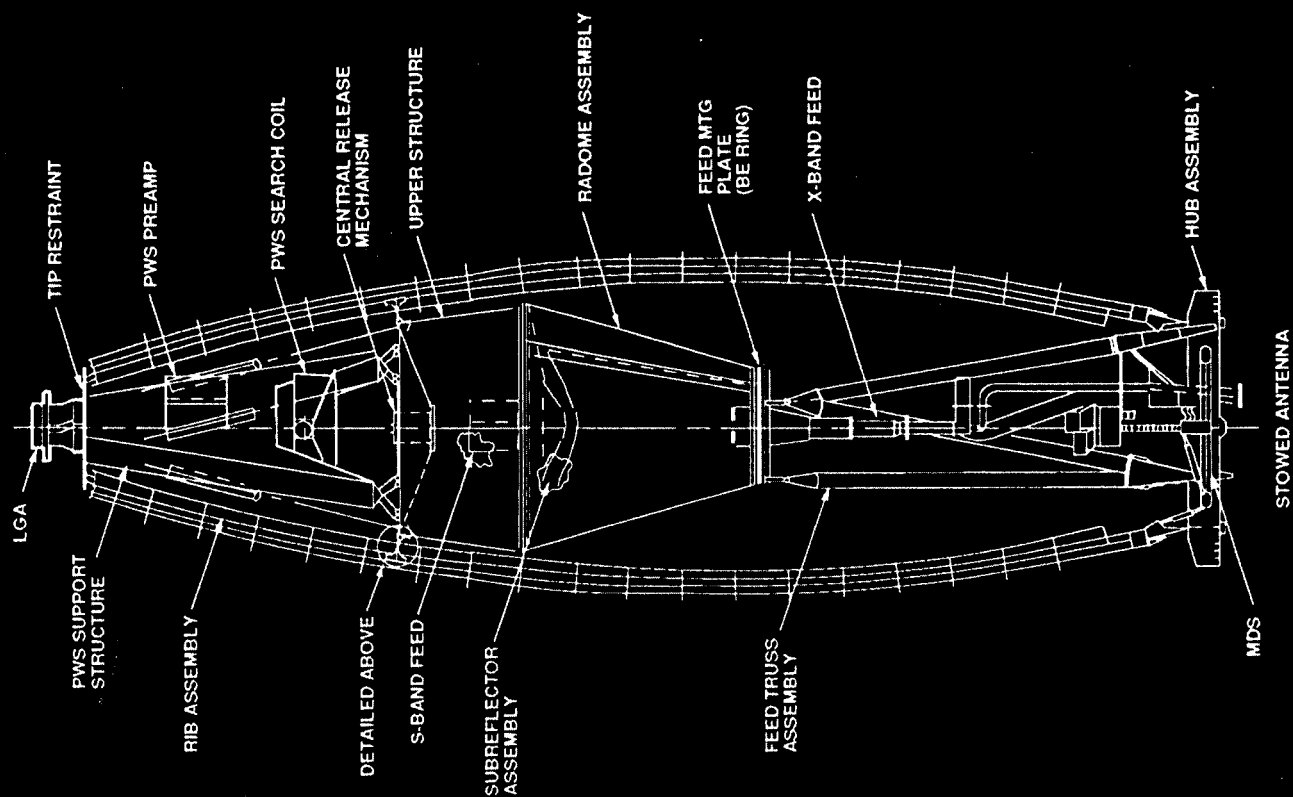
THE INSTRUMENT IS MOUNTED ON THE SPIN SECTION AND IS USED TO MEASURE THE SPIN RATE OF THE SPIN SECTION.





- 4.8 m deployable mesh antenna manufactured by Harris Corporation and delivered to JPL in 1983
  - Based on TDRSS design, but with substantial changes to accommodate mission-specifics and deep space environment
- Dual shaped Cassegrain optics at X-band with 49 dBi peak gain and 0.5° half power beamwidth
  - Hybrid mode feed provide dual circular polarization for simultaneous uplink and downlink
  - Enables peak data rate of 134 kbps from Jupiter
- Prime focus (front-fed) optics at S-band with 38 dBi peak gain and 1.8° half power beamwidth
  - Cavity mode feed provides dual linear polarization
- New, plane polar near field measurement technique developed by JPL to characterize Galileo high gain antenna RF performance







# High Gain Antenna Failure

Evidence for Partial Deployment,  
RF Performance Assessment,  
and an Unsuspected Cause



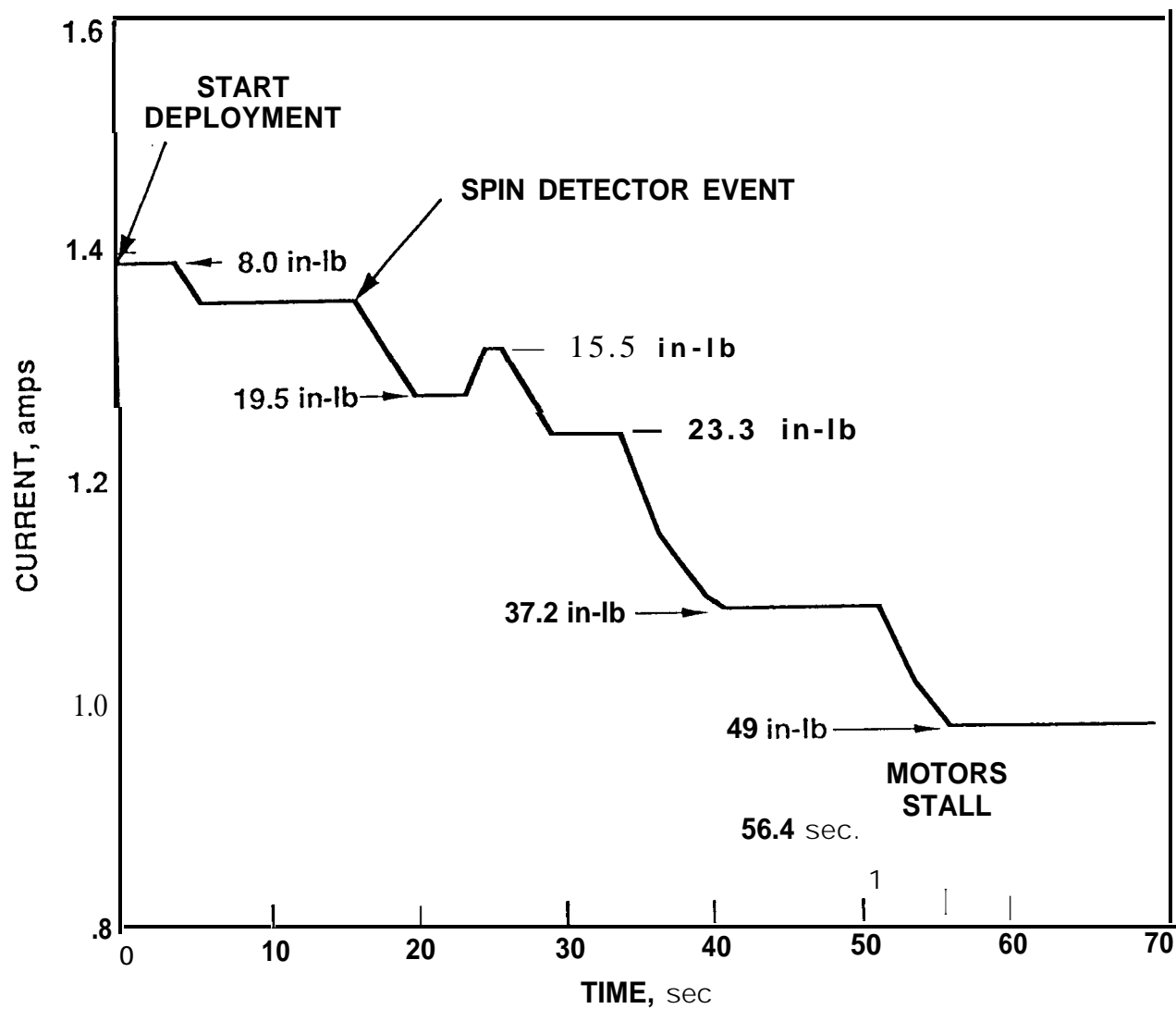
## The Evidence for Partial Deployment



- Attempted to unfurl the High Gain Antenna on April 11, 1991
- Deployment began nominally with positive <sup>SP</sup>indicatation for central release mechanism firing and normal motor currents
- At about 35 s into deployment, motor currents rise quickly
  - Motor stall condition reached at 56.4 s into deployment (nominal deploy time is approximately 3 minutes)
- Indication of partial obscuration from one sungate sensor (other opposing unit shows no obscuration)
- Shift in spacecraft “wobble” indicates assymetrical rib deployment and suggests (through modeling) a possible rib distribution



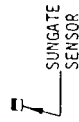
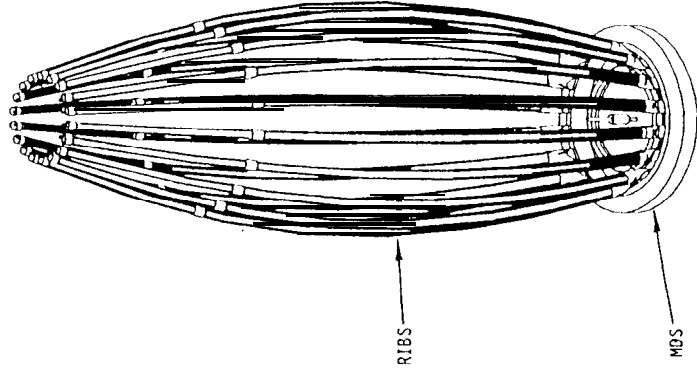
# HGA Motor Shunt Current vs Time



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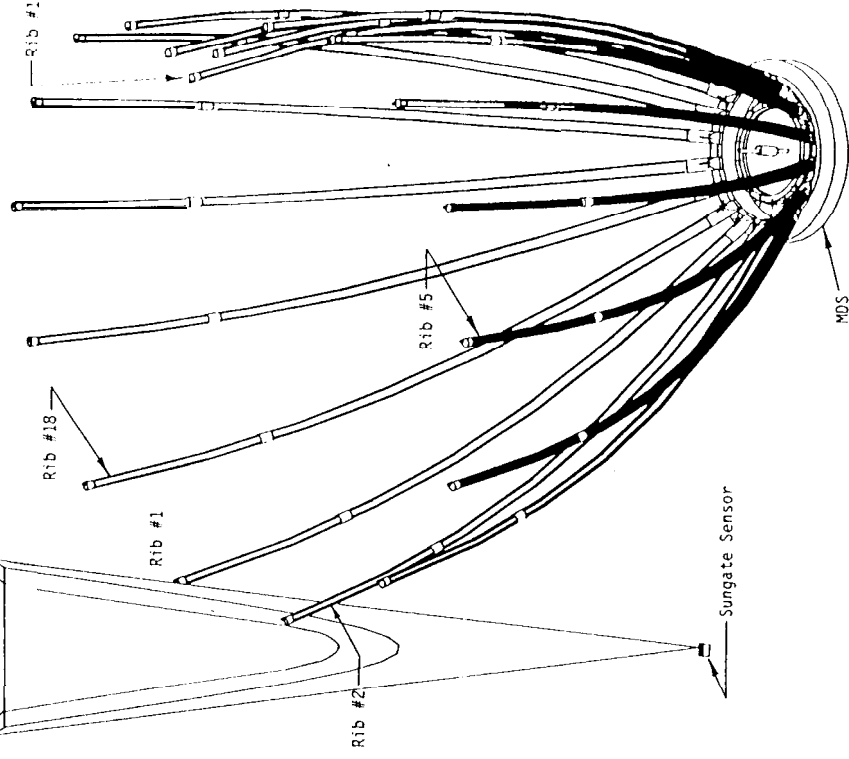


24-APR-91 14 03 38  
 DISPLAY NO STORED OPTION  
 Bln 1-M AIN  
 Component No stored COMPONENT



24-APR-91 14 03 38  
 DISPLAY NO STORED OPTION  
 Bln 1-M AIN  
 Component No stored COMPONENT

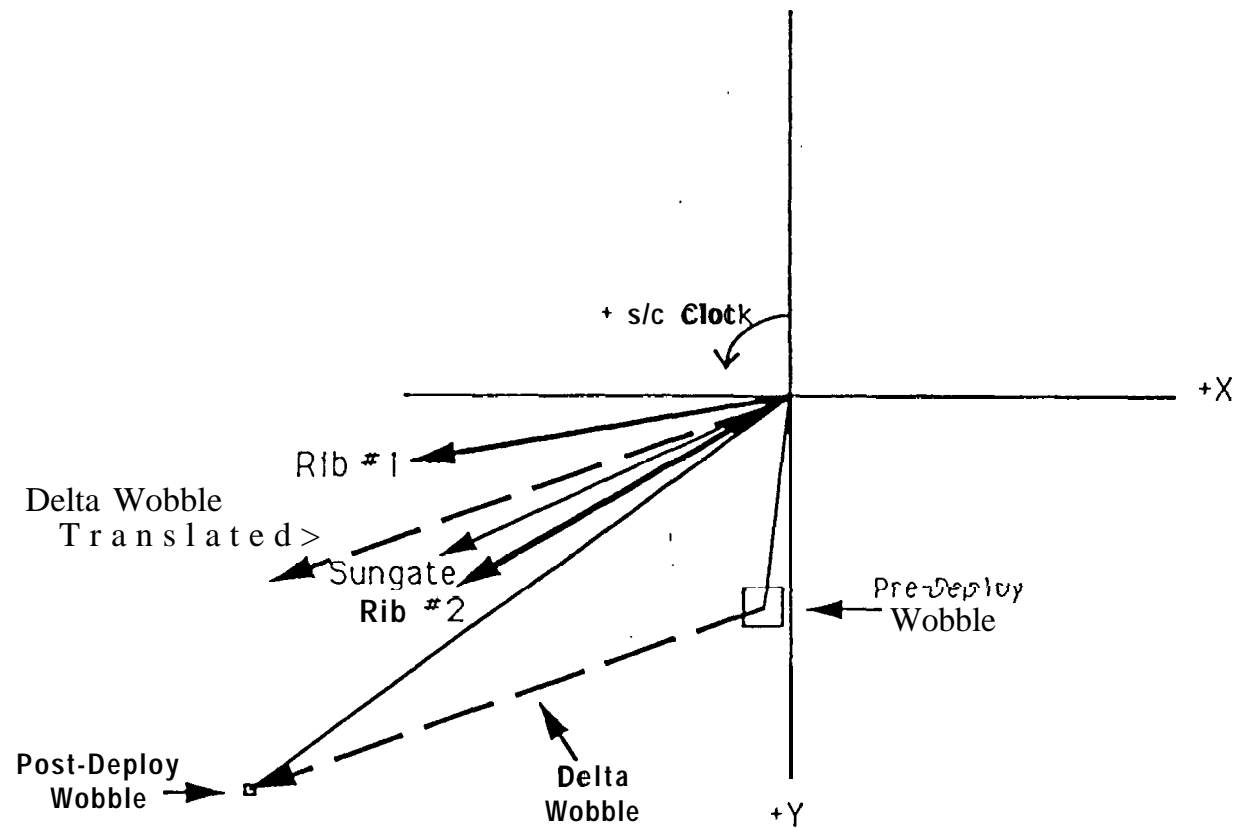
23-APR-91 19 32 04  
 DISPLAY NO STORED OPTION  
 Bln 1-M AIN  
 Component No stored COMPONENT



23-APR-91 19 32 04  
 DISPLAY NO STORED OPTION  
 Bln 1-M AIN  
 Component No stored COMPONENT

**Stowed Configuration**

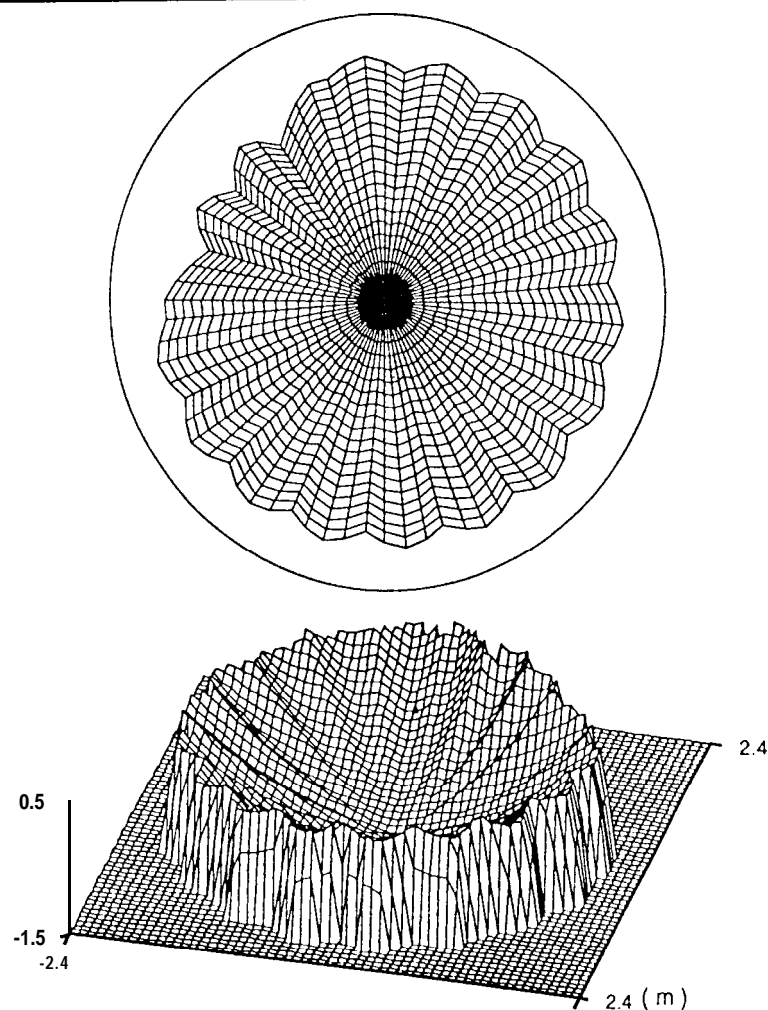
**Possible Asymmetric Deployment Scenario**



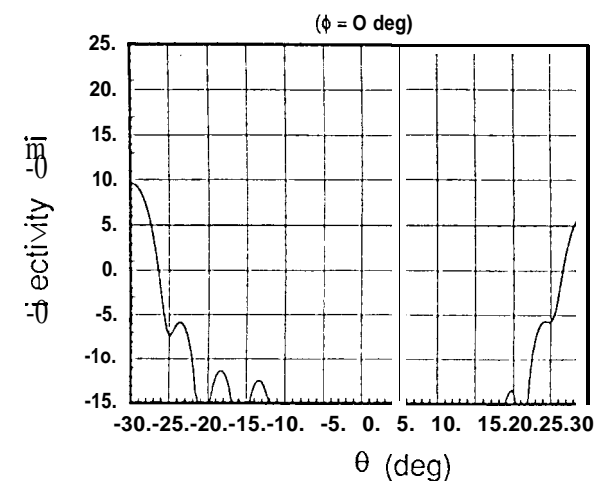
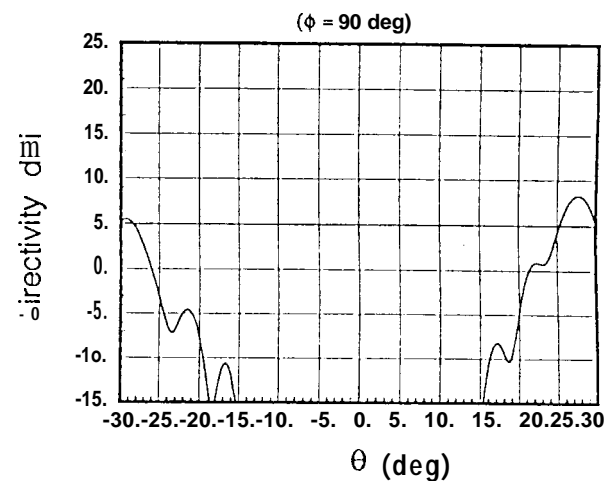
- Analysis & in-flight testing performed to assess whether:
  - any useable HGA performance might be available
  - RF data could be used to provide better insight into mesh and rib configuration
- Physical optics, GO/ GTD and finite element analysis techniques were initially attempted to characterize partially deployed HGA.
  - Results showed little probability of gains greater than 10 dB; however, large uncertainties introduced by analysis assumptions including:
    - » Single valued surface function (mesh doesn't fold over)
    - » Multiple bounces inside reflector not accounted for
    - » Central blockage ignored
- Phase retrieval techniques were identified to use holographic techniques on measured in-flight data to characterize aperture geometry



# Partial Deployed RF Performance, Cent'd



Aperture Configuration 24  
(ribs tilted at different angles)



Predicted S-Band HGA Patterns

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## Partial Deployed RF Performance, Cent'd



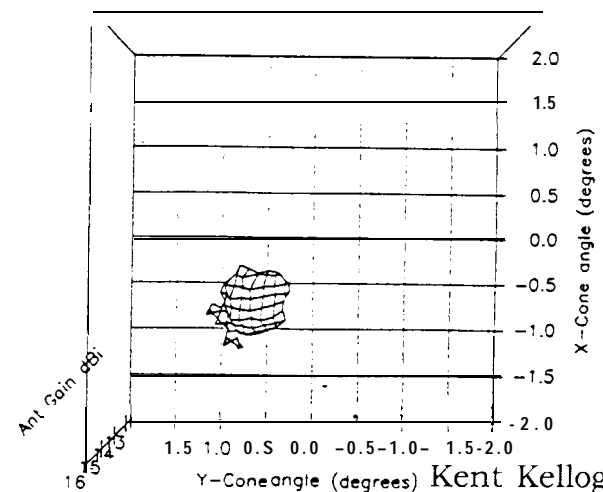
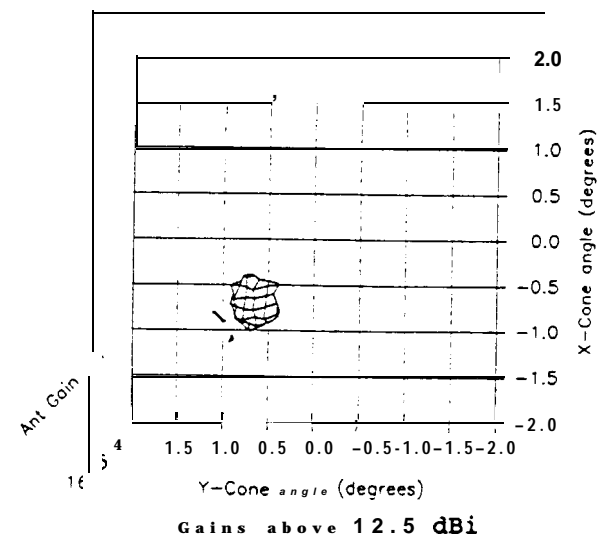
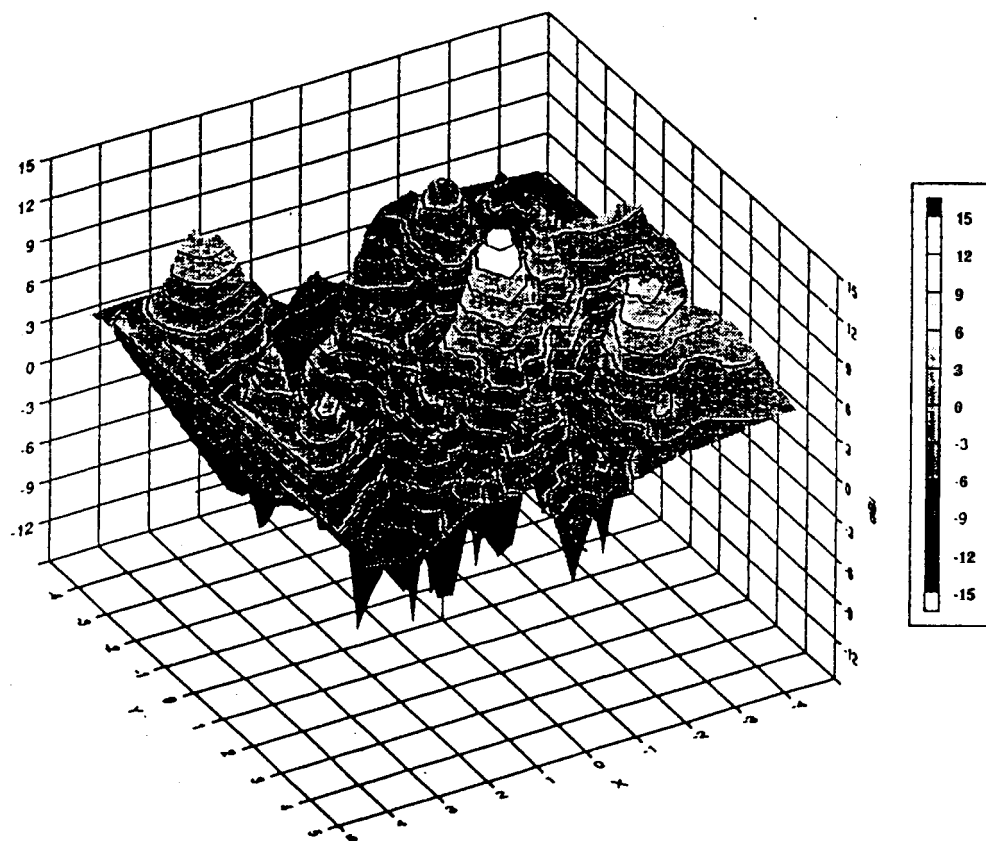
- In March 1993 a special in-flight test was performed to characterize S- and X-band HGA performance
- Spacecraft was swept from initial position of about 8° off Earth;
  - Through Earth-point to 5° off Earth;
  - back through Earth-point to 17° off Earth;
  - back to initial position
- “Sources” were DSS 14 (S-band) and DSS 15 (X-band)
- Spacecraft receiver AGC telemetry provided measure of antenna pattern gain
- Measured X-band peak gain of 14.8 dBi at 10° off HGA boresight
- Lobe with gain greater than 12 dBi over a 0.7° diameter
  - Lobe was found to be “spikey” with 1-2 dB gain variations



# In-Flight Measured X-Band Pattern



Gain pattern, perspective view



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## A Previously Unsuspected Cause

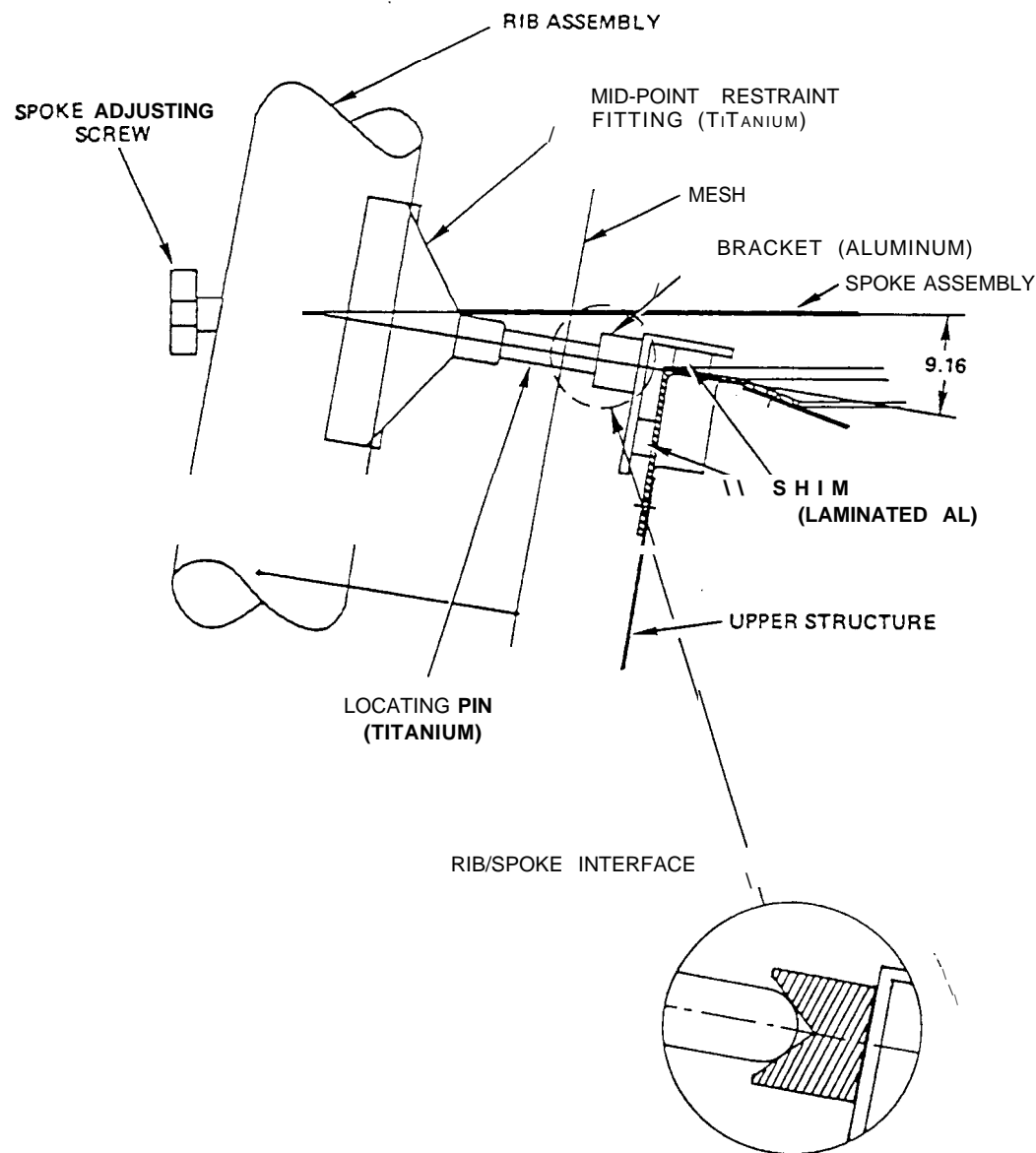


- Most likely failure scenario: four ribs stuck in mid-rib restraints
- Possible causes:
  - Loss of dry lube (moly-disulfide) and resulting metal-to-metal contact from wear and tear
  - Subsequent vacuum exposure (prevents oxide formation)
  - HGA tower thermal contraction
- $\pm$  X-axis restraints worn during shipping and single axis vibration
- In-flight deployment attempt transferred pin contact from restraint top to bottom
- Mis-aligned dagger pins stayed locked-in during deployment (taper lock)
- Rib flexure during deployment further increased pin load
- Ground testing simulating this failure on the spare HGA produced data very similar to that received from the spacecraft

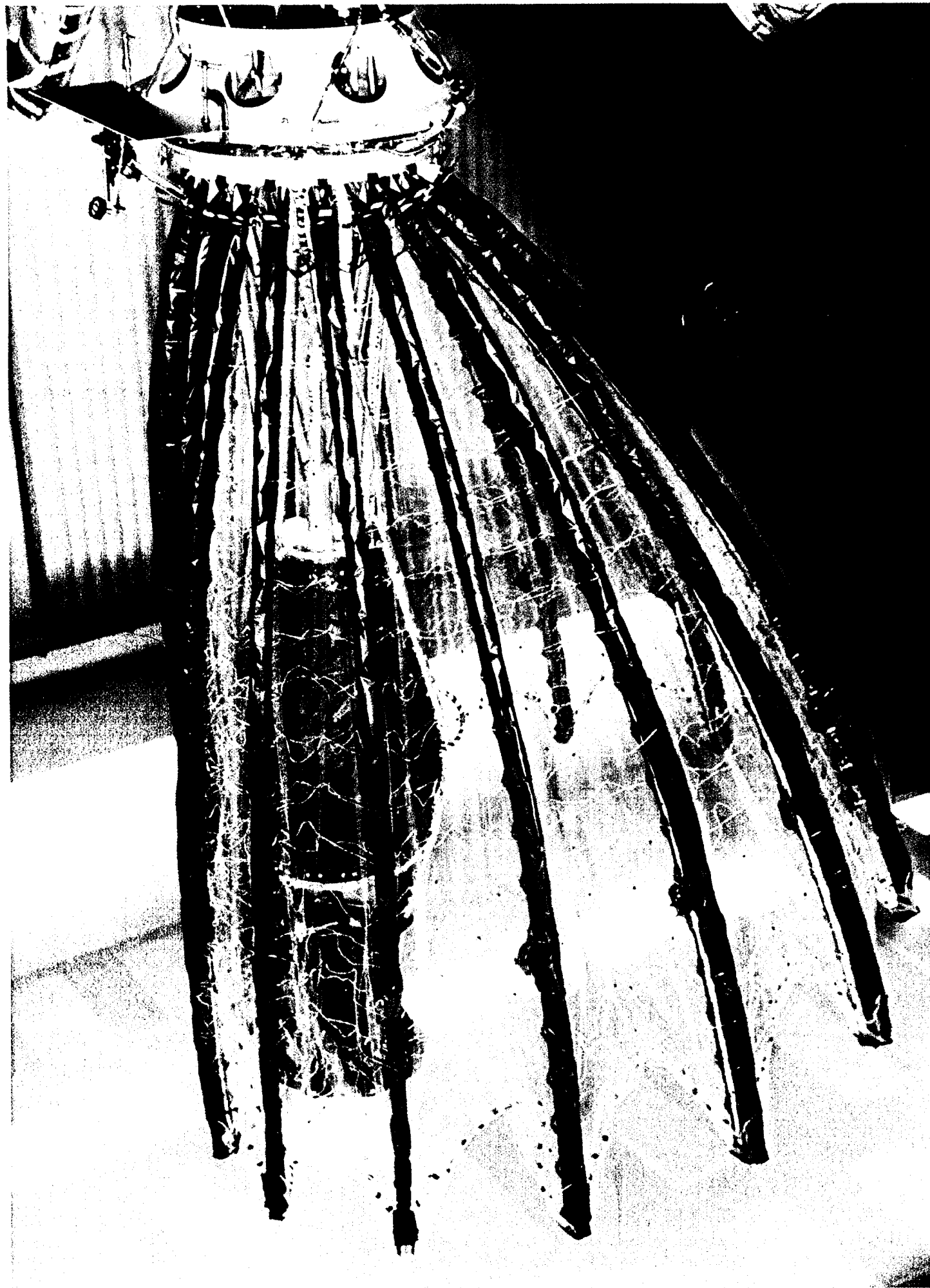
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# HGA Mid-Rib Restraint



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# Mission Recovery

Attempts to Free Stuck HGA,  
Mission Recovery Steps,  
Net Mission Impact

## Attempts to Free the HGA

- 
- First attempts to free the antenna were turning the spacecraft toward and away from the Sun to alternately warm and cool the ribs and thereby “walk” the stuck pins free
  - “Hammering” antenna deployment motors (on-off cycling) was thought to deliver sufficient force to free pins
    - 13,000 hammering occurred between December 1992 and January 1993
    - Engineering telemetry showed additional deployment force had been generated, but had not freed the ribs (rib 2 deployment angle changed from 35° to 43°)
  - Spacecraft spin rate increased from 3 rpm to maximum 10 rpm while also “hammering” deployment motors
  - Project determined there is no significant prospect of the antenna being deployed
    - A last attempt will be made in March 1996 when orbitor’s main engine fires and the spacecraft experiences its largest acceleration since launch

## THE GALILEO MISSION AT S-BAND: FORERUNNER....

**Galileo**



### *THE CHALLENGE*

- WITH THE FAILURE OF THE HIGH GAIN ANTENNA, THE MAXIMUM DATA RATE DROPPED FROM 134.4 KBITS/S TO 10-20 BITS/S
- 3-4 ORDERS-OF-MAGNITUDE REDUCTION IN RETURNED DATA
- TDA/GALILEO DEVELOPED A PRELIMINARY DESIGN IN 1992
- ENHANCED THE GROUND SYSTEM WITH AN INFUSION OF RECENT R&D
  - DATA COMPRESSION
  - ADDING/IMPROVING ANTENNAS
  - INTER-CONTINENTAL ARRAYING
  - NEW ERROR-CORRECTING CODING
- MODIFIED THE SPACECRAFT SOFTWARE
  - CDS/AACS SPARE MEMORY AND PROCESSING TIME MADE AVAILABLE
  - TMU COMMANDED TO SUPPRESSED CARRIER
  - PROGRAMMABLE SCIENCE INSTRUMENTS, 8 OUT OF 11, MODIFIED
  - DID EVERYTHING THAT WOULD FIT ON THE SPACECRAFT
- WITH THE NEW DESIGN
- HIGHEST DATA RATE IS 160 BITS/S
- ~70% OF ORIGINAL SCIENCE GOALS ARE ACHIEVED

# THE GALILEO MISSION AT S-BAND: FORERUNNER....

**Galileo**



## IMPROVEMENT IN DATA RETURN

MEGABITS  
RETURNED OVER  
THE MISSION

### UPGRADES

NO CHANGE

CODING, SUPPRESSED CARRIER, LISTEN ONLY

IMPROVED LINK BUDGETING

CANBERRA ULTRAONE

VARIABLE DATA RATE

GOLDSTONE/CANBERRA 70 M ARRAY

CANBERRA 34 M

COMPRESSION

(EFFECTIVE)

100 1000 10000 100000

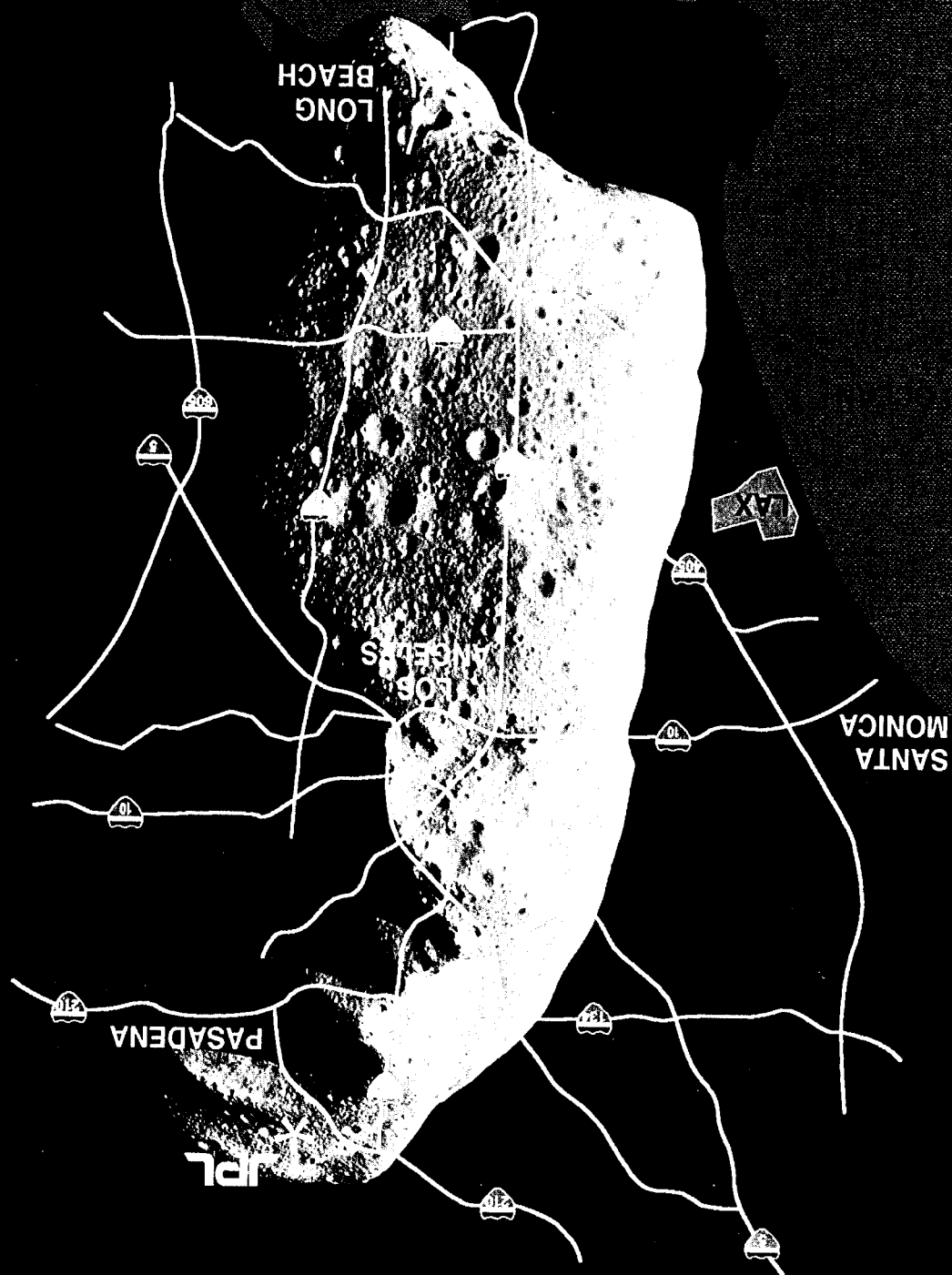


- 70% of original science objectives will be met by new telecommunications strategy
  - 100% of probe data will be returned
  - Nearly continuous, real time survey of Jovian magnetosphere for 2 years
  - Approximately 1500 images of 4 Galilean satellites, 4 inner minor satellites, and Jupiter and its rings
  - 11 very close encounters with Io (1), Europa (3), Callisto (3) and Ganymede (4)
- Specific impacts include
  - Color global imaging of Jupiter once per orbit eliminated
  - Global studies of Jupiter's atmospheric dynamics eliminated
  - Spectral and spatial coverage of moons reduced
  - fields & particles microphysics during cruise portion of each orbit reduced (to be retained for satellite encounters)

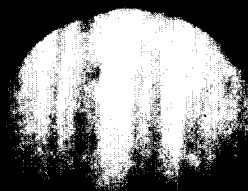
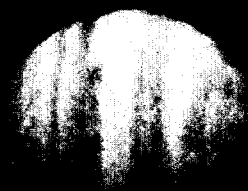
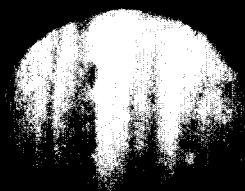
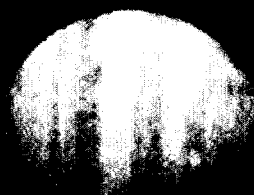


# Mission Accomplishments

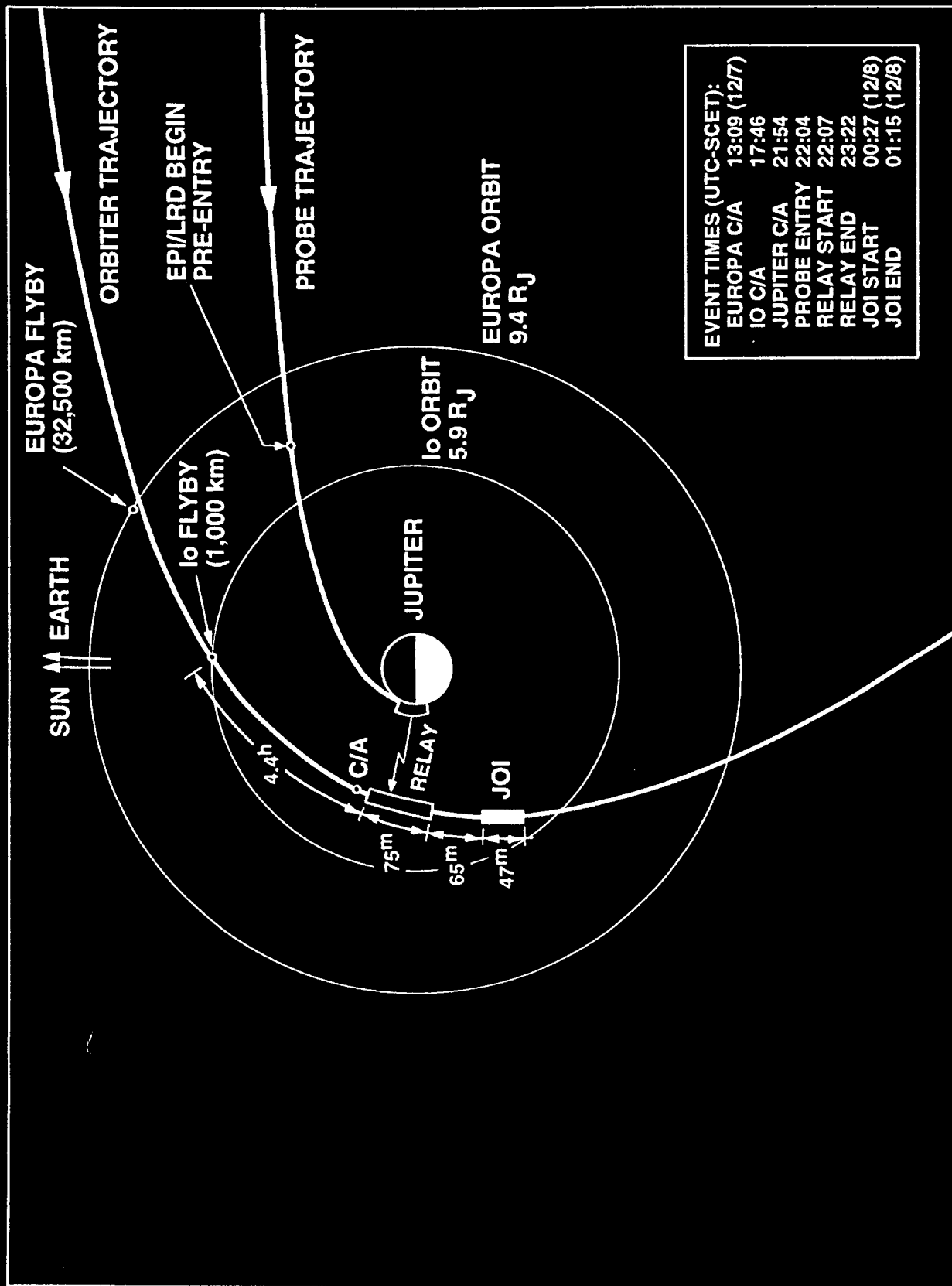








# JUPITER ARRIVAL (12/7/95)







## Participate!



•Galileo mission information (including images!) is available at

- JPL's WWW site at URL [http:// www.jpl.nasa.gov](http://www.jpl.nasa.gov)
- Galileo Project's WWW site at URL [http:// www.jpl.nasa.gov/galileo/ index.html](http://www.jpl.nasa.gov/galileo/index.html)
- Anonymous FTP access to general JPL site at [ftp.jpLnasa.gov](ftp://ftp.jpl.nasa.gov)
  - » Log on with user name "anonymous" and use E-mail address as password
- Modem access at (818) 354-1333

•Probe information and status reports are available at Ames Research Center WWW site

- URL [http:// ccf.arc.nasa.gov/ galileo\\_probe/](http://ccf.arc.nasa.gov/galileo_probe/)

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